Master 2 “Photonics, Complex and Quantum Systems (PhoCQS)”: Research Training 2025-2026

Appel à sujet de stage recherche / Call for research training subject

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Topic: Free-Electron Laser

Master 2: select the master and the most appropriate option

□ Master 2 PhoCQS (GP-IKS)	
□ Option Complex and Quantum Systems	

Title: **Modeling the Time-Dependent Evolution of FEL Pulses in Seeded Free-Electron Lasers**

Free-Electron Lasers (FELs) are based on the nonlinear interaction between the radiation emitted in a magnetic structure and a high-density relativistic electron beam. Accurate modeling of this process typically requires particle-in-cell simulations, which can reproduce key FEL features such as mode competition, superradiance, and saturation. However, these simulations are computationally demanding since they often track every electron in the bunch.
For time-independent FEL properties—such as gain length or output peak power—simplified analytical and semi-analytical models exist, providing fast estimates based on nominal beam and FEL parameters [1,2]. Recently, a new model has been proposed that extends these approaches to the time domain, enabling the prediction of spectral properties of seeded FELs with reasonable accuracy [3].
The goal of this project is to further develop this time-dependent model by including additional physical effects such as resonance conditions and evolving beam properties. The work will involve implementing the model in Python, validating it against state-of-the-art simulation codes such as Genesis [4], and applying it to reproduce experimental results obtained at FERMI [5].

[1] M. Xie, “Exact and variational solutions of 3D eigenmodes in high gain FELs”, Nucl. Instrum. Meth. A, vol. 445, pp. 59-66, 2000. doi:10.1016/S0168-9002(00)00114-5
[2] L. Giannessi, “Seeding and Harmonic Generation in Free-Electron Lasers”, in Synchrotron light sources and free-electron lasers: accelerator physics, instrumentation and science applications (Springer Berlin Heidelberg, New York, NY, 2016), vol. 115, pp. 195–223. doi:10.1007/978-3-319-14394-1
[3] F. Pannek et al., “Accurate control of seed and free-electron laser chirp with bunching spectral analysis”, in Proc. IPAC'23, Venice, Italy, May 2023, pp. 1954-1957. doi:10.18429/JACoW-IPAC2023-TUPL099
[4] https://genesis.web.psi.ch/aboutgenesis.html
[5] https://www.elettra.eu/lightsources/fermi.html

Key words: Free-Electron Laser; Seeded FEL; Harmonic generation; spectral control